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On an Instrument for Measuring the Positions and Magnitudes of Stars on Photographs and for Engraving them upon Metal Plates, with Illustrations of the Method of using the Instrument. By Isaac Roberts.

Celestial photography presents for investigation such vast numbers of stars that the necessity of finding new methods for dealing with them is pressed with force upon our attention. How we are to study the characteristics of several millions of stars is a problem pressing for immediate solution. The material for study will soon be abundantly supplied by the various international photo-astronomers when their instruments are erected, but hitherto those who are leading in this new science have apparently not advanced beyond the ideal of dealing with some two millions of the stars when they are photographed, and to them this number seems to be so large that in the lifetime of the existing generation of astronomers they can only hope to be able to leave behind them as a legacy to their successors huge volumes of figures deduced from some thousands of photographic plates.

Those successors, again, must rephotograph the heavens and in like manner produce their huge volumes of figures, and in the second or third generation from this it is anticipated that astronomers may sit down and endeavour to unravel the mysteries which may be lying hidden in the duplex series of figure volumes. This does not appear to be a satisfactory solution of the problem.

The preservation of the negatives so that they would for centuries be available for measurement and study would be a simple solution, but we know that the sensitised films on the plates that must at present be employed will not keep for centuries, and even if some future discovery should produce sensitised films that would be indestructible by lapse of time, or a method of vitrification should succeed, yet the glass plates, which of necessity would have to be frequently handled, could not be ensured against accidental destruction. Metal plates instead of glass might be coated with emulsion, and to ensure permanency each star might with a point be etched through the film and coating of wax upon the metal plates; but this method would be only the result of uncertain hand labour and would also involve the destruction of the photographs, instead of which they ought to be preserved for reference as long as possible. But without enumerating here the many difficulties which are more or less obvious and suggesting methods for the preservation of the glass negatives, we would ask, Are there not other ways of preserving with necessary accuracy the essential parts of the photographs, namely, the star positions and magnitudes? In answer to this question I submit the instrument and method which are the

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subjects of this communication, and which have occupied much of my attention during the past three years.

It is well known that copper plates may with ordinary care, and by use of simple means, be preserved for centuries, and if the star images could with accuracy be transferred from the negatives, without causing them injury, on to plates of copper or other metal, and then printed, and when necessary the plates also be duplicated and placed concurrently with the astro-photographic work in the hands of the astronomers of the present day, some of us might be permitted to see a portion of the fruits of our labours instead of leaving all to future generations. With the instrument now to be described the transference of the star images on to copper plates is both practicable and susceptible of great accuracy.

Description of the "Stellar Pantograver."

Plate I. shows the form and some of the details of the instrument.

A A A A are parts of the framework. The base plate and bridge on the top are of cast iron. The pillars are of brass.

B is a cast-iron platform, freely movable upon four anti-friction rollers, and guided by a V groove to run in a direction either towards or from the operator.

C is a platform of cast iron and guided in a similar manner to B, but in a direction at right angles to it, or in other words movable in a direction either right or left of the operator. Upon the top of this platform are placed the square stage D and the circular stage E, one to hold and secure the photograph and the other the copper plate to be engraved. The circular stage E is also made to rotate and serve as a large position-circle. It is 13½ inches in diameter, divided on the edge to degrees and five minutes of arc, and with the micrometer and microscope F can be read to seconds and fractions.

The movable platforms B and C have both a slow and quick motion. The slow motion is given by the screws of which G and H are the divided circular heads. The screws are of steel, ¾ inch in diameter, and cut 100 threads to the inch. The circular heads are five inches in diameter and divided on the edge to 100 equal parts; the value of one division is therefore 0·0001 of an inch, and by a vernier each division can be read to one-tenth, so that a distance traversed by either stage is measurable to 0·00001 of an inch.

K is a microscope bent at a right angle for convenience, and firmly held in the position shown over the circular stage E. The micrometer eyepiece M has webs which are placed at right angles to each other, and by one movement of the screw each pair of webs may be made to part asunder or to approach each other, as may be required, and form a common centre; thus each photographic star disc is viewed in the microscope with four spider webs

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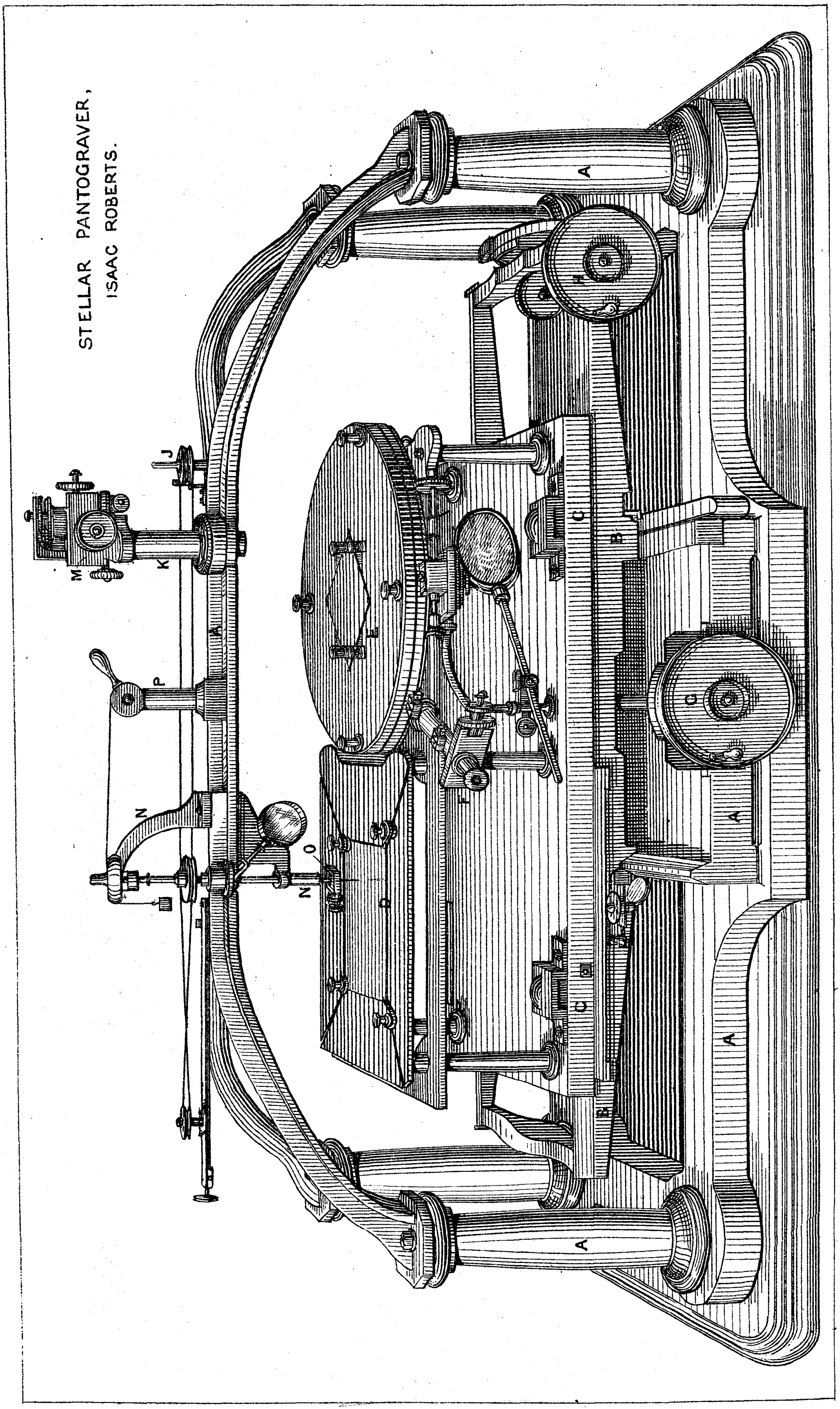

STELLAR PANTOGRAVER,
ISAAC ROBERTS.

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CIRCLES DRAWN BY ROBERTS' PANTOGRAVER.

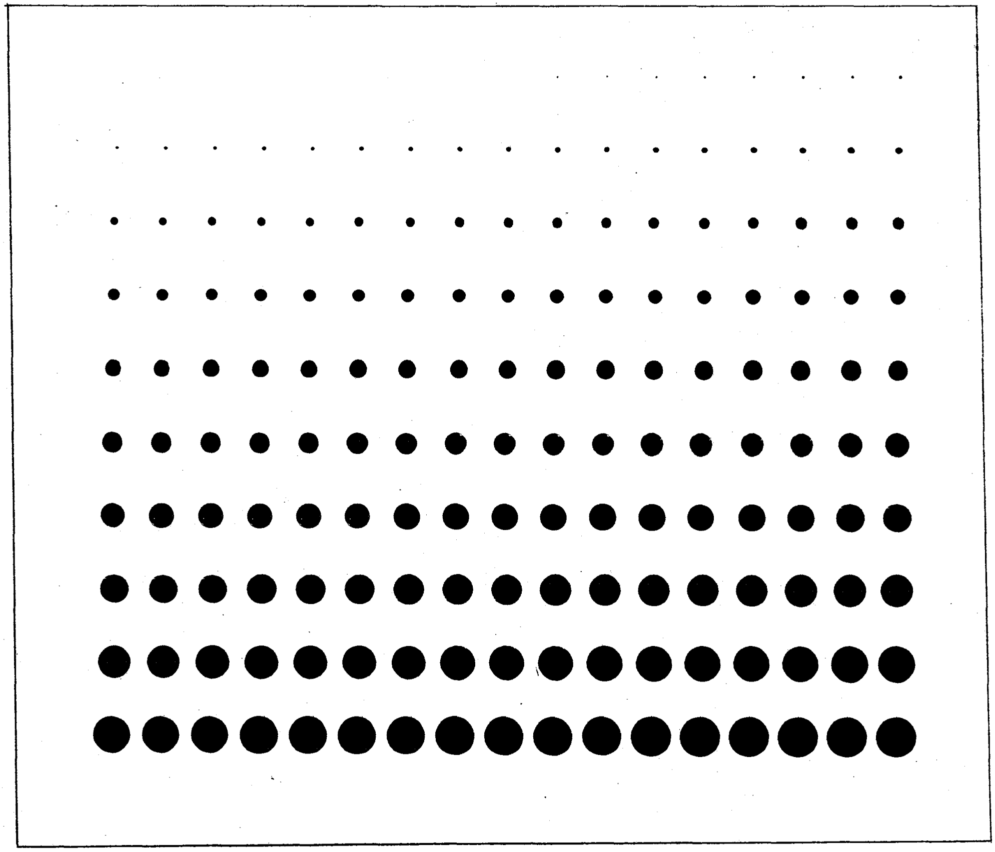

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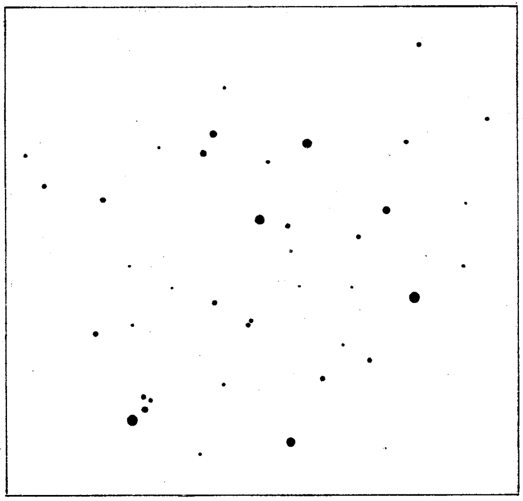
PLATE III.

ENGRAVED
FROM A NEGATIVE OF THE
·PLEIADES·
by PROF. PRITCHARD.



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placed tangentially against its margin, and the common centre of the webs is the centre of the star disc. The diameter of the star disc is measured to 0·0001 of an inch upon the heads of the screws of the micrometers. Two measurements at right angles are taken simultaneously, thus checking each other and at the same time showing if the star disc is round, together with the extent of deviation, if any, from the circular.

N is the engraving tool. It consists of a vertical steel shaft in gun-metal bearings. On the lower end of the shaft is fixed a micrometer, with screw cut 100 threads to the inch and head divided into 100 equal parts. The measurements are therefore made to 0·0001 of an inch, like those of the eyepiece micrometer. On the under side of the micrometer O is a steel pin carrying a fine diamond point, which is the graver, and it is fixed to a sliding piece attached to the micrometer screw, by the turning of which it is moved eccentrically to the extent required to trace a circle which is either equal to or is any proportion required of the star diameter on the negative. The readings of this micrometer are double those of the eyepiece micrometer, and by inspection and rotation of the heads of both these micrometers circles of any diameter from a point up to 0·16 of an inch can be traced with the diamond point of the graver.

P is a lever to lift the graver off the plate.

J is the wheel for rotating the graver.

Plate II. shows 160 circles which were traced upon copper, and afterwards transferred to lithographic stone and printed. The largest of the circles measures 0·16 of an inch in diameter, and each successive circle is 0·001 of an inch smaller in diameter than the one preceding it. The last is a point. The instrument is graduated so that circles can be drawn which will be either smaller or larger in diameter than each other within the limits of measurement.

From the foregoing statements it is apparent that a degree of accuracy in drawing stellar positions and magnitudes from the negative should practically be equal to the original negative, and, in order to demonstrate the closeness of theory with practice in this matter, I applied to Professor Pritchard for the loan of one of his negatives of the *Pleiades*, so that I might engrave the stars on copper plate, and he obligingly sent one that had been exposed for the same time as those used in the general determination of parallax; moreover he measured the engraved stars, as well as those which have been printed from the copper plate upon paper and shown in Plate III.

The following table gives the results of his measurements:—

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Results of Measurement of Star Distances on the Copper Plate of Pleiades compared with those of the Original Negative.

Names of Stars Measured (Bessel's Notation).	Distance on Negative in Inches.	Distance on Copper Plate in Inches.	Difference in Inches.	Difference in Arc.
	in.	in.	in.	″
From Maia to No. 4	0·11703	0·11609	0·00094	1·63
,, ,, Celeno	0·51980	0·51876	0·00104	1·80
,, ,, Electra	0·70567	0·70528	0·00039	0·67
,, ,, Wolf, No. 47	0·85096	0·85064	0·00032	0·55
,, ,, No. 1	0·72708	0·72788	0·00080	1·38
,, ,, Merope	0·91772	0·91711	0·00061	1·06
,, ,, No. 10	0·38450	0·38536	0·00086	1·49
,, ,, ρ	0·90537	0·90600	0·00063	1·09
,, ,, η	0·97170	0·97119	0·00051	0·88
,, ,, No. 21	0·98982	0·99016	0·00034	0·59
,, ,, Asterope	0·35427	0·35471	0·00044	0·76
,, ,, No. 5	0·55281	0·55235	0·00046	0·80 Mean 1″·06

Average Deviation of Bisections of Star Discs on Copper Plate.

0·00009 in. or 0″·16.

Average Deviation of Bisections of Star Discs on Negative.

0·00007 in. or 0″·12.

Comparison of Measures on Paper Print with Original Negative.

Names of Stars Measured (Bessel's Notation).	Distance on Negative in Inches.	Distance on Copper Plate in Inches.	Difference in Inches.	Difference in Arc.
	in.	in.	in.	″
From Maia to No. 4	0·11703	0·11688	0·00015	0·26
,, ,, Celeno	0·51980	0·51911	0·00069	1·19
,, ,, Electra	0·70567	0·70760	0·00193	3·34
,, ,, Wolf, No. 47	0·85096	0·85084	0·00012	0·21
,, ,, No. 1	0·72708	0·72966	0·00258	4·46
,, ,, No. 21	0·98982	0·99084	0·00102	1·76 Mean 1″·87

Five bisections were taken for each distance, and the mean of the five was taken.

The average discrepancy between the measures taken on the copper plate and on the negative is 1″·06.

Between the paper and the negative the average discrepancy is 1″·87.

It is found that the error (average) of bisection of a star on the original negative, compared with that on the copper plate, is as 3 : 4.

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The paper print was somewhat creased and probably hygroscopic. Prof. Pritchard adds, 'I regard this first attempt as eminently successful.'

It is desirable in the engraving of stars upon copper plates, with the view of printing them, that the photographic diameters should be increased at least twofold, or some other definite proportion, for if they are drawn only to the sizes on the negatives the faint stars are very small points which are difficult to see and measure. This can be done by the instrument.

I find a magnifying power of 24 with a field of two-tenths of an inch in diameter a very convenient one for viewing the stars on the negatives for engraving.

The instrument is adapted for cutting out the interiors of the star discs after their outlines are traced on copper plates, but it is a better plan to transfer the outlines on to lithographic stone and then fill in the interiors with a pen or brush. This saves both time and cost, and, what is of still greater importance, saves the plates themselves from injury by frequent pressure and wear. Many thousands of printed copies could thus be produced from one impression taken from the copper plate.

I find by experience that I can easily engrave 50 stars in an hour. If, therefore, an engraver worked during 8 hours a day for 48 weeks in the year, he would with one instrument transfer to copper plates 115,200 stars. If 20 instruments were thus employed during 10 years, 23,040,000 stars would be permanently placed on record, so that the astronomers of the present time could do great work, and afterwards leave their data unimpaired to the scrutiny of succeeding generations of astronomers in a form available for centuries to follow. Thus we should make a valuable contribution towards the solution of the great problems: Whence came our speck of Earth? Whither is it going?

The pantograver was made under my directions by Mr. Hilger, and I highly appreciate his skill in overcoming difficulties, and also the perfection of his workmanship, without which (or their equal) the success of the method would not have been attained.

Illustrations of the Method of using the Stellar Pantograver.

The machine is constructed of a size that plates which do not exceed eleven inches square can be engraved by it, and stars or other objects can be traced by an ordinary mechanic or other person to practically the accuracy of those on the plate or negative.

In using the machine a plate of glass the size of the negative to be engraved is ruled with parallel faint lines one-tenth of an inch apart, and in the case of a plate 4 inches square each line is numbered at the ends in consecutive order from 1 to 40. The plate is placed upon the stage under the observing microscope,

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with the ruled side uppermost. The negative is then placed and secured upon the glass plate with the film side down, and in contact with the ruled lines. This arrangement will ensure the stars when they are engraved upon the copper plates, and afterwards printed on paper, being in the same order of right ascension and declination as those on Argelander's chart. This, I submit, is desirable, because that chart will form a valuable key to the photographic chart, and is immediately available for the study of stellar changes.

The copper plate is next placed on the stage under the engraving point, and its position adjusted and fixed as required. As already stated the magnifying power I use in engraving is 24 diameters, and this gives a clear field of two-tenths of an inch in breadth. All the stars within the space enclosed by the lines are brought successively and accurately to the optical centre of the microscope between the four adjustable threads of the eyepiece micrometer, and the diameter or magnitude of each star is read off on the screw-head to 0·0001 of an inch. The same reading is then given to the screw-head of the engraving point micrometer. The point is then lowered to impinge upon the copper plate, and the tool handle twice rotated to cut the ring which represents the position and diameter of the star on the negative. In this way each star on the negative can be engraved both accurately and expeditiously, and without unduly taxing the attention of the operator, at the rate of 50 to 60 stars an hour. If any uncertainty should at any time arise as to whether any star has or has not been engraved, the resetting of the instrument will at once determine it, and specks or other defects in the film can with certainty be detected and eliminated.

The accuracy of the work done by the machine has been tested in various ways besides those already referred to, but the following example will suffice. Four stars at distances apart of 0·35 inch and 0·46 inch on a negative were selected and brought successively under the microscope and then engraved on a copper plate, first as a point in the centre of each; then a series of concentric circles were drawn round the central point, the instrument being moved freely by hand in any direction between each operation of drawing the central point and circles. At the completion of the operations the circles were practically concentric with the central point and with each other.

Plate IV. is a chart of 1,270 stars within a circle of one degree of the North Pole as the centre, and it was engraved from a negative taken on the 14th of August this year, with an exposure of 105 minutes. The diameter of the circle is two degrees. Carrington and Argelander on their charts show 38 stars on this area, and they are distinguished on Plate IV., as nearly as I could recognise them (for they do not all coincide), by the white circles with a black spot in the centre.

This chart of the Polar circle will serve as an illustration of

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the importance to working astronomers of this method of engraving, printing, and circulating without delay the work of the photo-astronomers, both international and private, for it places in their hands a strongly marked index showing them at a glance the exact spots in the sky, where perceptible changes in the positions and magnitudes of the stars have taken place since the dates of the several published charts.

The fact being established by inspection, measurements, or eye alignments that changes according to the charts have taken place among the stars, there is obvious necessity for measuring the negative or copper plate and use of the transit instrument, and in a few months' time after publication of the photographic chart there will be ample work for all the astronomers in the world to determine whether those differences are due to actual changes in the objects or to errors in the charting, and then will follow computations and evolution of laws which will occupy their lifetime and those of succeeding generations of astronomers.

These suggestions for immediately utilising the existing charts by comparison with the photographic chart, would suggest that modifications should be made in the international scheme for the formation of a catalogue of some two million stars, and, instead of the proposed 15 minutes' exposure of the plates, at least an exposure of 60 minutes to a clear sky ought to be substituted, and the stars charted to the faintest magnitude such an exposure would imprint even as a stain on the films. By these modifications of the scheme, a chart of the sky worthy of the resources of the present day would immediately be commenced, and within the next ten years accurately printed copies showing all stars down to the 16th or 18th magnitude would be in the hands of all persons interested in astronomical investigations.

I have now shown, and I think demonstrated, the practicability of the scheme for engraving. The question of the form in which the printed charts should be issued could be answered in at least two commendable ways: *first*, with four photo-squares on each leaf in a book of strong paper; *second*, as separate photo-squares on octavo sheets of strong paper, and numbered in consecutive order and with an index, the sheets being kept loose in book boxes containing 500 each, so as to be available for micrometric measurements. This I think would be the most convenient method, as will be seen if we proceed to consider the way that astronomers would be likely to adapt for themselves their future work, which we will assume to be somewhat in the following order, namely:—

Astronomer A is desirous of investigating the stars within the radius of one degree of the Pole as a centre, and is possessed of the printed charts and an instrument of precision for measuring. He knows in which country the photo-astronomical work of this region is done, and he also knows the bureau where the negatives and engraved plates are kept. The bureau ought to be in

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a building forming part of or contiguous to the national observatory of each country, and under the control of the national astronomer. Our typical astronomer, having studied the printed chart and therein found matter requiring closer investigation, requests the head of the bureau to send him a copper-plate duplicate of the original, of the sky space indicated, and with his request remits the standard fee. In due course he receives what is practically the original negative (the copy being exact), and then resumes his investigations, and within a brief interval of time he is in a position to inform the astronomical world that he has found something new to tell.

The method hitherto followed in designating stellar magnitudes by numerals and decimal parts will not be the most desirable in the new photo-astronomy, as will be evident on examination of the microscopic gradations of the engraved circles representing the star discs. The determination of magnitude should no longer be empirical, but be the result of exact measurement by micrometer, and in place of assuming a given number of magnitudes such as 1st or 18th, there may be one hundred or more measurable magnitudes between the brightest star and the faintest on any negative or copper-plate copy, or printed chart. The future designation may be in parts of an inch or of a millimetre.

In the pantograver the eyepiece and engraving micrometers are divided to measure 0·0001 of an inch, and if the star discs on the negatives were both circular and sharply defined on the edge, estimated measurements to 0·00002 of an inch could be made and registered as the stellar magnitude; but in practice these conditions seldom occur, and the edge of the disc is undefined, by reason, probably, of atmospheric tremor and glare; hence measurements of magnitude will be ± 0·001 of an inch, and the gradations would therefore be somewhere within this limit. If the disc of the brightest star, say *Sirius*, were represented on the photograph by 0·08 of an inch, and the faintest star by 0·002 of an inch, there would by the gradation here suggested be seventy-eight measurable stellar magnitudes, each one of which would be distinctly recognisable by measurement.

The pantograver is also an instrument of precision for measuring stellar distances and position-angles. Any distance not exceeding 11 inches can be measured theoretically to 0·00001 of an inch in two directions at right angles to each other, and in my photo-telescope, which is 98 inches focal length, one second of arc is equal to 0·00476 of an inch, being a large measurable quantity.

There are many details connected with the subject-matter of this paper that I must defer for future discussion.

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Chart of 1,270 *North Polar Stars.*

The following are the positions and magnitudes of the 38 stars on Argelander's chart, which are shown as *white circles* on the accompanying engraved photo-chart (Plate IV.).

Magnitude.	Right Ascension.	Declination.	Magnitude.	Right Ascension.	Declination.
	h m s	° ′ ″		h m s	° ′ ″
9·5	0 11 5	89 36 2	9·5	12 0 23	89 26 3
9·2	1 17 35	0 2	8·8	12 59 20	28 3
8·8	1 49 36	29 2	8·7	13 3 53	8 7
9·4	1 50 57	23 6	9·4	13 25 6	32 6
9·5	1 51 58	13 3	9·5	15 3 47	24 2
9·4	2 16 43	0 6	9·0	15 14 45	40 9
9·3	3 11 12	4 3	9·5	15 44 3	55 1
9·5	3 53 49	0 5	9·5	15 45 16	2 8
9·1	4 49 39	27 1	8·7	17 21 38	18 4
9·5	5 43 44	6 0	9·4	18 7 27	43 8
9·5	5 57 3	3 6	9·3	18 42 30	9 5
9·1	6 17 38	37 9	9·5	19 29 17	38 0
7·0	7 3 40	1 8	9·5	19 37 46	12 9
9·5	7 14 2	1 0	9·5	19 45 0	27 5
9·2	7 27 50	1 6	9·3	19 56 5	14 3
9·5	8 58 47	39 4	9·3	20 13 29	45 9
9·0	10 26 21	32 0	9·5	21 8 21	31 7
8·9	11 8 27	43 9	9·3	22 6 40	48 0
9·5	11 9 11	32 9	9·0	23 21 18	0 8

On a Compensating Pendulum. By Richard Inwards.

The pendulum about to be described must not be taken as novel in all its parts. So much has been done that such entire novelty would now be impossible. But what I hope is that the general arrangement with its many new features may result in a substantial improvement on existing forms.

In accurate pendulums in which the temperature compensation is obtained by the expansion in contrary directions of tubes of zinc and steel, there has always been a great difficulty in at once apportioning the respective lengths of the rods or tubes used for the purpose.

This difficulty arises in a great measure from the fact that no two specimens of the metals can be readily obtained having exactly the same coefficient of expansion. Particularly with the zinc is